National Energy Board | Office national de l'énergie

Investigation under the *National Energy Board Act*

In the Matter of:

9 July 2006 ruptures of the Pine River Gas Plant Sulphur Pipeline, owned and operated by Westcoast Energy Inc. carrying on business as Spectra Energy Transmission

June 2009

Canada

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List of Abbreviations and Definitions

ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
black-start	Start up of the plant and equipment from a state of zero power
DCS	Distributed Control System
HAZ	Heat affected zone
HB	Brinell hardness
HRB	Rockwell B hardness
HRC	Rockwell C hardness
HV	Vickers hardness
Joules	Measure of energy. Used to measure impact energy.
ksi	kilopounds per square inch, 10^3 pounds per square inch
kPa	kilopascals, 10^3 pascals
ft-lbf	Foot-pounds force. Used to measure impact energy.
LBV	Line Block Valve
MOP	Maximum operating pressure. In the case of the sulphur pipeline, the MOP was set at the design pressure of the pipeline.
MPa	Megapascals, 10^6 pascals
NEB Act	*National Energy Board Act*
OPR-99	*Onshore Pipeline Regulations, 1999*
PPR	*Processing Plant Regulations*
PRGP	Pine River Gas Plant (the Plant)
psi	pounds per square inch, unit of measure
SECT	Skin-Effect Current Tracing
SMYS	Specified Minimum Yield Strength
Spectra	Short for the legal name: Westcoast Energy Inc. carrying on business as Spectra Energy Inc.
sulphur pipeline	Pine River Gas Plant Sulphur Pipeline (the pipeline)

Chapter 1

Summary

At approximately 0200 Mountain Daylight Time (MDT) on 9 July 2006, near Chetwynd British Columbia, the 168.3 mm diameter Pine River Gas Plant Sulphur Pipeline (the sulphur pipeline or the pipeline), operated by Westcoast Energy Inc. carrying on business as Spectra Energy Transmission (Spectra), experienced ruptures at 2.3 km and 2.8 km. On 3 July 2006, lightning activity at the Pine River Gas Plant damaged two electrical power generators and caused a loss of power to the sulphur pipeline's heat tracing system. Instrumentation readings for the sulphur pipeline were lost on 4 July 2006 and a decision was made to shut down the pipeline. This allowed liquid sulphur to solidify within the pipeline. During re-melt procedures, expanding liquid sulphur and hydraulic shock developed internal pressures which caused stress in excess of the material tensile strength and ruptured the pipe at 2.3 km and 2.8 km. In both occurrences, no injuries were sustained and the sulphur did not ignite. An approximate total of 2 m^3 of molten sulphur was released from the pipeline and later recovered.

The National Energy Board (NEB, or the Board) has concluded its investigation and has made ten (10) findings as to the cause of the accident and the factors contributing to it, and two (2) decisions relating to the prevention of future similar accidents. The decisions form the basis for Order SC-W102-01-2009.

Chapter 2

Scope and Objectives of Investigation Under the *National Energy Board Act* (NEB Act)

The scope of the NEB investigation into this accident was determined in accordance with the Board's mandate as set out in the NEB Act, more particularly, subsection 12(1.1):

> *12(1.1) The Board may inquire into any accident involving a pipeline or international power line or other facility the construction or operation of which is regulated by the Board and may, at the conclusion of the inquiry, make*
>
> *(a) findings as to the cause of the accident or factors contributing to it;*
>
> *(b) recommendations relating to the prevention of future similar accidents; or*
>
> *(c) any decision or order that the Board can make.*

In light of the authority of the Board set out under subsection 12(1.1) of the Act, the objectives of the NEB investigation were to: gather all evidence related to the accident; conduct an analysis of the evidence; make findings as to the cause or factors contributing to it; make recommendations relating to the prevention of future similar accidents; and make any decision or order the Board can make, as appropriate, to prevent similar accidents from occurring.

Chapter 3

Factual Information

3.1 The Pine River Gas Plant Sulphur Pipeline

The sulphur pipeline is located near the town of Chetwynd in Northeastern British Columbia. The local geography is mountainous and the pipeline descends a steep slope approximately 5.5 km long, experiencing a 490 m elevation change. Appendix I illustrates the geographic location of the sulphur pipeline. Appendix II provides a schematic diagram of the sulphur pipeline.

The sulphur pipeline was constructed in 1994[1] for the purpose of transporting liquid sulphur from the Pine River Gas Plant (PRGP or Plant) to a pelletizing facility operated by an independent company near Hasler Flats. The pipeline system is comprised of 168.3 mm (NPS 6) diameter pipe and fittings constructed to the standard ASME B31.3[2], above ground supports, multiple heat tracing systems, and thermal insulation. The pipe specifications are summarized in Table 2-1.

Table 2-1
Sulphur Pipeline Specifications

Length	5.5 km
Pipe Specification	ASTM A 106[3] Grade B Schedule 80
Elbow Specification	ASTM A 234[4] WPB Schedule 80
Diameter	168.3 mm (6.625 inches or NPS 6)
Wall Thickness	10.97 mm (0.432 inches)
Yield Strength	240 MPa (35 ksi)
Ultimate Tensile Strength	415 MPa (60 ksi)
Maximum Operating Pressure (MOP) or Design Pressure	10 584 kPa (1 535 psi) @ 177°C (350°F)

The Pine River Gas Plant operates on a self generating power system with 5 generators totaling 10.5 MW of primary capacity. Units GE3401A and 3401B are 3 MW generators driven by natural gas fired turbines. Units GE14.03 and 14.04 are 1.5 MW generators driven by natural gas fired reciprocating engines. Unit GE14.01 is a 1.5 MW generator driven by a steam turbine. One 70 kW emergency generator supplied power to emergency lighting and critical control systems. Surge arresters were in place on exposed overhead power lines.

1 Construction and operation of the Sulphur Pipeline was approved by Order XG-W5-28-93, dated June 1993, pursuant to section 58 of the *National Energy Board Act*.

2 ASME B31.3 Chemical Plant and Petroleum Refinery Piping, 1990 ed.

3 ASTM A 234 – Standard Specification for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and High Temperature Service

4 ASTM A 106 – Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service

The sulphur pipeline transports sulphur in a liquid state maintained above the melting point of 115.2 °C. Sulphur may expand in volume by 8.3% or more upon remelting (phase change from monoclinic solid to liquid). Properties of sulphur are detailed in Appendix III. At normal flow rates, sulphur in the pipeline stays at sufficiently high temperatures to reach the terminus without solidifying. The sulphur pipeline utilizes heat tracing, insulation, and other back up systems to prevent solidification at low flow rates.

Three heat tracing systems provide heat to the sulphur pipeline. The length of the pipeline is heated by Skin Effect Current Tracing (SECT), which is powered by the Plant electrical generators. An illustration of the SECT heat tracing system is provided in Appendix IV. The SECT system provides inductive and resistive heat through a 33.4 mm (NPS 1) conduit joined to the pipeline by tack welds approximately every 300 mm. A glycol jacket heating system is installed from the Plant to the beginning of the pipeline, approximately 25 metres downstream of valve 30ESDV002. A mineral insulated electric heat tracing system is installed at line block valves (LBVs), with the LBV 1 system powered by Plant electrical generators and LBV 2 powered by BC Hydro.

The pipeline is insulated by 76 mm (3 inches) of pearlite covered by an additional 76 mm (3 inches) of polyurethane foam. Pipe supports have greater thermal conductivity and are therefore locations with greater heat loss. Additional insulation is installed at these locations. When sulphur is flowing, variations in heat loss occur over the length of the pipeline, but do not affect operation. When sulphur is not flowing, areas that experience higher heat loss are at greater risk of solidification.

A nitrogen injection skid is available to assist draining of the pipeline without introducing air. The nitrogen gas is electrically heated to prevent cooling and solidification of sulphur during the procedure. Power is supplied to the nitrogen skid by the Plant electrical generators.

The sulphur pipeline is supported on piles above ground. Shoes are installed to accommodate lateral shifts. At specific locations, the pipeline is restrained to supports with anchors and tie-rods to withstand dynamic loads such as hydraulic shock. The pipeline is restrained as expansion joints to keep the pipe positioned on its pipe supports where it is installed on steep terrain.

3.2 Incident Narrative

On 3 July 2006 at 2136 MDT, lightning struck the Pine River Gas Plant. Generation electrical protection devices, load shedding devices and system instability caused total loss of power. The surge in voltage damaged the two 1.5 MW generators driven by natural gas fired reciprocating engines, which were the only units capable of black-starting the plant. Attempts to restart the generators were unsuccessful. The Plant's Distributed Control System (DCS), which provides computerized monitoring and control, continued to operate on battery power.

The loss of power at the Pine River Gas Plant rendered the sulphur pipeline heat tracing systems inoperable. The SECT and mineral insulated electric heat tracing at LBV (1.5 km) were inoperable without electrical power from the Plant. With the Plant shut down, Sulphur production ceased.

On 4 July at 0113 MDT, sulphur from storage was used to establish a 325 tonnes/day minimum flow rate to prevent solidification of sulphur within the pipeline. At 1020 MDT battery power for the DCS had been completely consumed. Operators were unable to accurately monitor the pipeline without the DCS and stopped flow from storage. Without electrical power, the nitrogen injection skid was not available to support draining the pipeline, and the pipeline shut-in valves were closed. By 1440 MDT, the sulphur remaining in the pipeline began to solidify.

On 6 July, power was restored to the Pine River Gas Plant and the DCS. Remelt procedures commenced at approximately 1900 MDT and the sulphur pipeline's SECT heat tracing system was energized. The remelt procedure required a controlled temperature increase over a period of up to 70 hours.

On 8 July at 2108 MDT, a leak was observed at LBV2 (3.2 km) and operators were dispatched to conduct repairs. A short time later, on 9 July at 0200 MDT, an operator at 3.2 km heard a single loud explosion. At 0550 MDT a rupture was identified at 2.8 km and at 0556 the remelt procedure was suspended. The Transportation Safety Board[5] (TSB) was notified by telephone on 9 July at 1105 MDT and the NEB was subsequently notified by telephone at approximately 1140 MDT.

On 13 July, staff from the NEB and TSB attended the site of the incident. After a preliminary assessment of the facts surrounding this incident, the TSB determined that it would not conduct an investigation. The NEB therefore continued with a full investigation pursuant to the NEB Act.

The sulphur pipeline sustained ruptures at 2.3 km and 2.8 km, as well as damaged anchors and displacement of the pipe from its supports at 1.5 km, 2.3 km, and 2.8 km. The condition of the pipe was examined by removing insulation at piles along the pipeline. Measurements confirmed the pipeline had expanded in diameter by as much as 3.8% near the 2.3 km rupture and 5.7% downstream of the 2.8 km rupture[6]. The rupture at 2.3 km occurred on the inside radius of the last 90 degree elbow of an expansion joint. The anchors were damaged and the pipe was completely displaced from its supports. The rupture at 2.8 km occurred on a straight section of pipe located on a slope. Pipe at this location was displaced on its supports.

In both occurrences, no injuries were sustained and the sulphur did not ignite. An approximate total of 2 m^3 of molten sulphur was released from the pipeline and later recovered.

In the period following rupture, Spectra voluntarily removed the sulphur pipeline from service to conduct its investigation and implement corrective actions. On 26 April 2007, after Spectra had undertaken repairs and corrective actions, the NEB's Operations Business Unit, Business Leader

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5 The TSB is an independent agency created to advance transportation safety through the investigation of occurrences associated with the operation of an aircraft, a ship, a pipeline, or rolling stock on a railway, to determine cause and contributing factors. If the TSB investigates an occurrence associated with the operation of a pipeline, the NEB can only investigate that occurrence for reasons other than determining the cause and contributing factors. In that instance, the NEB would coordinate its investigation through the TSB.

6 Spectra Energy Inc., Pine River Gas Plant Liquid Sulphur Pipeline July 2006 Line Breaks and Repair, 19 September 2007, Appendix B.

advised that there were no outstanding concerns that precluded the return the sulphur pipeline to service[7].

3.3 Laboratory Examination of Failed Pipe

The failed sections of pipe were submitted to Acuren Group Inc. (Acuren) for independent analysis. The conclusions presented in Acuren's analyses[8 9] were supported in a review performed by the Transportation Safety Board's Engineering Branch[10]. The National Energy Board accepts and adopts these conclusions in its determination of the causes of failure.

3.3.1 Elbow Failure at 2.3 km

The failure of the elbow at 2.3 km was caused by internal pressure which developed stress in excess of the ultimate tensile strength of the fitting. High stress caused expansion of the pipe diameter and thinning of the pipe walls.

Inspection of adjacent straight sections of pipe indicated the pipe diameter was 1.91 mm to 5.46 mm (0.075 to 0.215 inches) oversize. Pipe wall thickness measured 7.11 mm (0.280 inches), 35% less than the specified wall thickness of 10.97 mm (0.432 inches).

The hardness of the elbow material adjacent to the fracture was measured between 226 HV and 298 HV. The hardness of a typical cross section measured 190 HB (91 HRB), which is lower than the 197 HB maximum specified in ASTM A 234.

Tensile properties were determined by cutting and straightening a piece of the elbow. The yield strength could not be reliably determined because of the strain effects of straightening, however the specimen met the ultimate tensile strength and elongation specified by ASTM A 234. Appendix V details the results of tests performed on the elbow.

3.3.2 Pipe Body Failure at 2.8 km

The failure at 2.8 km was caused by internal pressure which developed stress in excess of the ultimate tensile strength of the pipe. High stresses expanded the pipe diameter and caused thinning of the pipe walls.

Inspection of adjacent straight sections of pipe indicated the pipe diameter was 4.98 mm to 9.53 mm (0.196 to 0.375 inches) oversize. Pipe wall thickness measured 7.72 mm to 10.03 mm (0.304 to 0.395 inches), 9% to 30% less than the specified wall thickness of 10.97 mm (0.432 inches).

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7 National Energy Board, Westcoast Energy Inc. ("Westcoast") Spectra Energy Transmission Pine River Gas Plant – Sulphur Pipeline Incident of July 2006, 26 April 2007.

8 Acuren Group Inc., Pine River Sulfur Line: Elbow Failure, 29 August 2006.

9 Acuren Group Inc., Pine River Sulfur Line: Pipe Failure, 29 August 2006.

10 Transportation Safety Board of Canada Engineering Branch, Engineering Report LP097/2006, 23 January 2007.

The fracture initiated at a crack located in the toe of a tack weld joining the SECT conduit to the pipe. A cross section at this location revealed secondary cracking in the root of the tack weld. Magnetic particle inspection revealed crack indications at 7 of 10 adjacent tack welds.

Hardness adjacent to the fracture was measured between 241 HV and 298 HV; while hardness in the HAZ and tack weld were measured between 343 HV and 364 HV. The hardness of a typical cross section measured 190 HB (92 HRB). The standard ASTM A 106 does not specify a maximum hardness, but for comparison the hardness is less than the maximum specified by ASTM A 234.

Tensile test results met the requirements of ASTM A 106. These results and the Charpy V-Notch impact energy values are summarized in Appendix V.

3.4 Previous Incidents

Since commissioning in 1994, the sulphur pipeline has experienced a number of incidents including a series of fires as a result of sulphur leaks in 2000 and 2001. In March 2001, the Board appointed an investigative panel and eventually ordered all work on the pipeline to be stopped[11]. An oral hearing[12] was convened in Chetwynd British Columbia between 9 and 12 April 2001.

In its Reasons for Decision, dated October 2001, the Board found the sulphur pipeline did not operate as expected due to a combination of design problems, unanticipated operating conditions, and inadequate maintenance and operational procedures. To address these operational concerns, Spectra drafted and implemented a Comprehensive Plan and was granted conditional approval to open the sulphur pipeline[13].

One condition of approval required Spectra to advise within one week of restarting the pipeline that all work necessary to upgrade the pipeline supports to accommodate hydraulic shock had been complete. The condition was later amended[14] to allow Spectra to operate the pipeline but not undertake any remelting activities until the upgrades were complete. All work necessary to upgrade the pipeline supports to withstand a major hydraulic shock had been undertaken by September 2002.

11 National Energy Board, Miscellaneous Order MO-06-2001, 16 March 2001.

12 National Energy Board, Miscellaneous Hearing Order MH-1-2001.

13 National Energy Board, Order XG-W005-33-2001, 17 October 2001.

14 National Energy Board, Amending Order AO-1-XG-W005-33-2001, 16 November 2001.

Chapter 4

Results of the Investigation Under the NEB Act

This section presents the results of the investigation under the NEB Act in terms of the:

- Findings as to cause of the accident and factors contributing to it (pursuant to paragraph 12(1.1)(a) of the NEB Act);
- Corrective actions taken by Spectra; and
- Decisions the Board has made that relate to the prevention of future similar accidents (pursuant to paragraph 12(1.1)(c) and subsection 48(1.1) of the NEB Act).

4.1 Total Loss of Power at the Pine River Gas Plant

4.1.1 Findings as to Cause and Contributing Factors

Finding 1.	The total loss of power at the Pine River Gas Plant was caused by a lightning strike within 2 km of the Plant.

At 2136 MDT on 3 July 2006, the Pine River Gas Plant experienced a total loss of power. Using Vaisala Fault Finder® software, Spectra confirmed that lightning struck the plant, within a 1 km radius range of error, at the time of power loss.

Finding 2.	Inadequate surge protection and lack of redundant or emergency power to black-start the Plant were factors contributing to the total loss of power at the Pine River Gas Plant.

The initial total loss of power was caused by a combination of inadequate surge protection, activation of trip devices on the reciprocating generators, and load shedding device activation. The plant subsequently could not be restarted due to the failure of the reciprocating generators and lack of alternate emergency power to black-start the plant. At the time of the incident the surge arresters were only installed at overhead powerlines. The Plant was susceptible to power surges in the unlikely event of a direct lightning strike. Generating units GE14.03 and 14.04 (driven by natural gas fired reciprocating engines) were to be used to black-start the Plant in the event of total power loss. After the lightning strike, these units could be started, however they sustained damages that prevented energizing the main bus[15] and power could not be restored to the Plant. Further, the emergency generator only provided power to emergency lighting and critical systems.

15 General Electric Canada, GE Canada Report, 21 July 2006.

4.1.2 Corrective Actions Taken By Spectra

Spectra has since upgraded the electrical system with greater surge protection and added redundancy for emergency power generation.

High capacity surge arresters were added at each generator and the main bus. Distribution type surge arresters on overhead power line systems were replaced with higher capacity station type surge arresters.

A dedicated 600 kW emergency generator was added to the electrical system. The emergency generator provides emergency power for black-start of GE3401-A and 3401-B generators, for the sulphur pipeline nitrogen injection skid, and for the Train 3 battery chargers that support critical systems.

4.1.3 Decisions Relating to Prevention of Similar Future Accidents

Decision 1. Spectra shall within six (6) months of the published date of this report, submit to the Board a summary report assessing all existing operating gas plants within its NEB regulated operating system for:

a) adequacy of surge protection installations, particularly regarding whether upgrades similar to those implemented at the PRGP are warranted; and
b) availability of emergency power for black-start of generators.

The Board makes Decision 1 to ensure that electrical systems at all other gas plants within Spectra's NEB regulated operating system have adequate surge protection and emergency power for black-start capabilities. This will prevent similar periods of prolonged loss of power and unforeseen upset operating conditions which may occur as a result.

4.2 Solidification of Sulphur in the Pipeline

4.2.1 Findings as to Cause and Contributing Factors

Finding 3. The root cause of solidification of sulphur within the pipeline was inadequate planning for prolonged total loss of power.

The scenario of prolonged total loss of power was not adequately planned for in the design of the nitrogen injection skid, shutdown procedures, and operating procedures. The operation of the electrically heated nitrogen injection skid was dependant upon full restoration of power. Sulphur pipeline shutdown procedures relied upon the operability of the nitrogen injection skid. Sulphur pipeline operating procedures did not contemplate operation without monitoring capabilities from the DCS. Without the ability to monitor the pipeline, and a lack of prepared contingency in such a scenario, operators shut-in the sulphur pipeline. With electrically powered heat tracing inoperable the sulphur began to solidify.

Finding 4. Factors contributing to solidification of sulphur and the formation of sulphur plugs include:

a) The inability to drain the pipeline.
b) The inability to continue operation after loss of power to the DCS.
c) Inoperable electrically powered heat tracing.
d) Higher heat loss at pipeline supports, pull-boxes and junction boxes, and other discontinuities.

As similarly described in relation to Finding 3, the inability to drain the sulphur pipeline, due to a lack of emergency power supply, was a contributing factor in the series of events that led to solidification of sulphur within the pipeline. Additionally, since operators could not maintain operation without the DCS, the decision to shut in the sulphur pipeline was also a contributing factor. As well, the electrically powered heat tracing was inoperable and unable to prevent solidification.

Pipeline supports, pull-boxes and junction boxes, and other discontinuities contributed to solidification of sulphur and the formation of solid sulphur plugs because these locations have higher thermal conductivity or varying insulation. The coincidence of sulphur plugs at these locations was confirmed by radiographic examination after the 9 July 2006 ruptures and by thermal imaging.

4.2.2 Corrective Actions Taken By Spectra

A dedicated 600 kW emergency generator has been installed by Spectra since the incident which will provide power for the nitrogen injection skid, for black-starting one of the site's primary jet generators, and for plant battery charger supply, in addition to other emergency power system items.

The procedure for a total power outage[16] was revised to provide clear and concise instructions for the sulphur pipeline. Specifically, a minimum flow rate of 1000 tons/day is to be established from storage and if power is not restored within two hours, or storage is low, the pipeline is to be drained and purged.

For the 2006 re-melt, Spectra installed temporary supplemental heating and insulation at various locations on the pipeline to mitigate against heat loss at locations with high thermal conductivity. After remelt activities were complete, the temporary items were removed and the line was restored to its permanent design state.

4.2.3 Decisions Relating to Prevention of Similar Future Accidents

The Board is of the view that the corrective actions taken by Spectra have greatly reduced the risk of solidification of sulphur within the pipeline in the event of a total power loss. The Board has no additional decisions to make in this respect.

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16 Spectra Energy Inc., PRGPCR16 Total Power Outage, rev. 5, 1 May 2007.

4.3 Overpressure

4.3.1 Findings as to Cause and Contributing Factors

Overpressure was caused by two mechanisms, or a combination thereof: expansion of sulphur during phase change from solid to liquid and/or hydraulic shock. The overpressure mechanisms and their relevance to failure at 2.3 km and 2.8 km are explored further below.

When liquid sulphur solidifies it contracts and effectively packs the pipeline. Upon remelting, the packed sulphur expands during the phase change and creates extreme localized pressures. Hydraulic shock is caused when a slug of solid sulphur releases and creates out-of-balance forces and pressure rarefaction[17], or when liquid sulphur travels through a void in the pipeline and hits an obstruction such as a plug of solid sulphur, a turn in an expansion joint, or a closed valve.

Finding 5.	The overpressure at 2.8 km was likely caused by expansion of sulphur during phase change from solid to liquid between plugs of sulphur.

The overpressure at 2.8 km was likely caused by expansion of sulphur during phase change from solid to liquid between plugs of solid sulphur. The pipe experienced significant wall thinning adjacent to the SECT conduit, where expansion from phase change would be greatest. The effects of overpressure by expansion of sulphur during phase change are cumulative with each successive overpressure. Expansion of the pipe can occur each time the pipeline is subjected to the remelt procedure. Lab results from examination of the failure at 2.8 km showed no evidence of progressive failure; however, the pipe diameters at locations along the line expanded by up to 7% and are now at greater risk of cumulative effects.

Finding 6.	The overpressure at 2.3 km may have been caused by pressure or rarefaction wave, or hydraulic shock, resulting from the 2.8 km rupture in combination with the expansion effects of melting sulphur.

As reflected in finding 6, the cause of overpressure at 2.3 km is not entirely certain. Thinning of the elbow wall adjacent to the failure may be indicative of localized overpressure associated with expansion of sulphur during phase change. However, this bulging did not occur adjacent to the SECT conduit. Spectra has suggested that hydraulic shock, as a result of out-of-balance forces and pressure rarefaction created by the 2.8 km rupture, may have contributed to overpressure. This would explain the uphill/upstream displacement of the expansion joint at the 2.3 km rupture site.

Finding 7.	The root cause of overpressure was an inadequate remelt procedure.

17 Spectra Energy Inc., Pine River Gas Plant Liquid Sulphur Pipeline July 2006 Line Breaks and Repair, 19 September 2007, 8.

The purpose of the remelt procedure[18] was to return the sulphur pipeline to service after it had been inoperative for several days and the sulphur was totally or partially solidified. The procedure called for a series of controlled temperature increases and hold periods over a span of up to 70 hours.

In practice however, when the remelt procedure was initiated upon restoration of power, the controlled temperature increases and hold periods could not be achieved (the time-temperature profile is provided in Appendix VI). The uneven heating observed during the remelt procedure may have been a result of initiating the procedure when: temperatures varied greatly throughout the pipeline (between 52°C and 163°C); sulphur in the pipeline was at varying degrees of solidification; sulphur plugs and voids were present; there were heat sinks at discontinuities in the pipeline; or any combination thereof. Ultimately, the remelt procedure was unsuccessful and resulted in uneven temperatures and overpressure conditions that eventually ruptured the sulphur pipeline.

4.3.2 Corrective Actions Taken By Spectra

The procedure for remelting the sulphur pipeline was extensively revised[19]. The procedure now has a pre-condition for remelting, which is to ensure complete solidification of sulphur remaining in the pipeline by maintaining uniform temperatures below 37.8°C (100 F) for a 24 hour period. The new remelt methodology requires rapid heating of the heat tracing systems, which will melt a channel of sulphur immediately next to the heat tracing. This minimizes the volume of sulphur that will undergo phase change and expand. The sulphur pipeline is also to be melted in 7 pre-planned sections. The procedure identifies large commitments of time, resources, equipment, and monitoring, required to remelt the pipeline, as well as the need for every remelt to be analyzed by a team prior to execution.

In March of 2007, while the new procedure was being used to remelt the sulphur pipeline, the pipeline did not remelt uniformly and experienced hydraulic shock[20]. As a result, an anchor and tie-rod assembly was damaged but the pipe did not rupture. Subsequently, a full remelt was achieved in April of 2007 without further damage.

4.3.3 Decisions Relating to Prevention of Similar Future Accidents

The Board has no additional decisions to make in this respect. The Board acknowledges that performing a remelt without occurrence of hydraulic shock is difficult, if not impossible to achieve. Extensive research and field trials by Spectra have resulted in a more effective remelt procedure. The Board also notes that other corrective actions taken as a result of this incident have greatly reduced the probability of sulphur solidifying within the pipeline, and therefore reduced the probability of having to perform a remelt procedure. Nonetheless, should the sulphur pipeline require a remelt again in the future, Spectra should undertake careful analysis and perform the remelt with great diligence.

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18 Spectra Energy Inc., PRGPSPL01 Sulphur Pipeline Remelting Procedure, rev. 5, 3 April 2003.

19 Spectra Energy Inc., PRGPSPL01 Sulphur Pipeline Re-Melting Procedure, rev. 6, 3 December 2006.

20 Spectra Energy Inc., Pine River Gas Plant Liquid Sulphur Pipeline July 2006 Line Breaks and Repair, 19 September 2007, 19.

4.4 Ruptures at 2.3 km Elbow and 2.8 km Pipe

4.4.1 Findings as to Cause and Contributing Factors

Finding 8. The immediate cause of failure at both the 2.3 km elbow failure and the 2.8 km pipe failure was stress exceeding the tensile strength of the material.

The total loss of power, solidification of sulphur in the pipeline, and overpressure upon remelting, eventually led to ruptures at 2.3 km and 2.8 km on the sulphur pipeline. Laboratory examination of the failed material at both locations revealed acceptable material properties and the cause of failure was determined to be stress exceeding the tensile strength of the material.

Finding 9. A crack in the heat affected zone of the weld joining the SECT conduit to the pipe was a contributing factor of the rupture at 2.8 km.

A crack in the toe of the weld joining the SECT conduit to the pipe at 2.8 km contributed to the failure only by providing a site for the rupture to initiate. The cause of the crack which contributed to failure at 2.8 km was investigated further. Spectra submitted to the Board a sample quality control (QC) package for joining of the SECT conduit to the pipe during fabrication. The QC package included welding procedure specifications, welder qualification, and non-destructive examination records that included 100% NDE of tack welds by magnetic particle inspection. The sample record demonstrated effective NDE which identified linear crack indications and resulted in rejection and repair of welds.

Investigation of the cut-out from the pipe body failure at 2.3 km by Acuren revealed significantly higher hardness in the heat affected zone (HAZ) than in adjacent material, additional cracks at 7 of 10 adjacent tack welds detected by magnetic particle inspection, and a secondary crack in the root of the tack weld was revealed by cross-section of the failure surface.

A number of conclusions can be drawn from these observations. The higher hardness measured in the HAZ than in adjacent material would suggest that hardness was pre-existing and a result of the welding process. Material with higher hardness could have provided stress concentration and a site for crack initiation. Also, since cracks in 7 of the 10 adjacent tack welds were detected by magnetic particle inspection and the QC process was demonstrated to be effective, it is possible that the cracks initiated some time after fabrication or during overpressure at the time of the remelt. What caused initiation of the secondary crack in the root of the tack weld is less certain, but highlights the need for strict adherence to the welding procedure specification to reproduce welds free of defects.

4.4.2 Corrective Actions Taken By Spectra

Spectra has since performed a series of measurements to determine the degree of expansion along the sulphur pipeline. As well, Spectra performed a hydrostatic pressure test and compiled

a brief qualitative risk assessment[21] to assess the integrity of the sulphur pipeline as it relates to MOP.

The results of measurements along the sulphur pipeline are compiled in two plots, provided in Appendix VII. Measurements of the outside diameter were plotted against distance in Figure VII-1, with the range of specification ASTM A 106 for comparison. Expansion proved to be greatest in locations near the 2.3 km and 2.8 km ruptures and exceeded the range of the specification. Measurements of the wall thickness were also plotted against distance in Figure VII-2, with minimum and nominal wall thickness of specification ASTM A 106 for comparison. All wall thickness measurements were greater than the minimum specified by ASTM A 106.

On 17 and 18 April 2007, the sulphur pipeline was subject to a hydrostatic pressure test in accordance with ASME B31.3, CSA Z662, and Spectra's internal specifications. The test was deemed successful upon completion of an 8 hour strength test and a 4 hour leak test. Pressure was maintained between the 21 375 kPa (3100 psi, or 2.02 x MOP) minimum and the 22 754 kPa (3300 psi, or 2.15 x MOP) maximum test pressures[22].

The strength test achieved a minimum pressure of 21 526 kPa (3122 psi, or 2.03 MOP). In terms of stress, the test produced a minimum hoop stress of 165 MPa or 69% SMYS. In comparison, the pipeline design pressure of 10 584 kPa produces a hoop stress of 81 MPa (34% SMYS).

The risk assessment included integrity threats such as pipe defects, corrosion, geotechnical or third party, and operational. Spectra determined pre-existing or newly initiated cracking and hardness associated with the tack weld were not a threat to long term integrity. Spectra submitted that significant thinning and bulging from stress beyond the yield strength, and the high failure stress, were evidence that cracks and hardness have not degraded the original design of the pipeline. Further, the hydrostatic test indicated that all possible defects that remain survived the maximum operating pressure and safety factor of 2.

Spectra determined the threat of internal corrosion was highly unlikely, however it is mitigated by corrosion monitoring units, which are monitored quarterly, and ultrasonic testing points.

To mitigate threats concerning geotechnical issues or third party damage, Spectra conducts routine ground patrols.

Spectra determined operational upset to be the greatest risk to integrity of the sulphur pipeline. Operational upset refers to conditions outside of normal operation that could lead to solidification of sulphur in the pipeline, performing of remelt procedures, and hydraulic shock. To mitigate against these threats, Spectra made extensive revisions to operating procedures and increased protection and redundancy of electrical systems. In the event of serious operational upset, Spectra has committed to development of a specific testing program to determine the suitability of the pipeline for continued service, similar to actions taken prior to the April 2007 return to service.

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21 Spectra Energy Inc., Long-term Integrity Plan Development, 15 September 2008.

22 Unless otherwise stated, the noted test pressures are measured at the pipeline terminus.

4.4.3 Decisions Relating to Prevention of Similar Future Accidents

Decision 2.	Spectra shall, within six (6) months of the published date of this report, submit to the Board: a) a proposed plan for conducting ongoing periodic assessments of the integrity of the sulphur pipeline system based on sound engineering principles and related industry-recognized standards. Consideration shall be given to the effects of the normal and abnormal operations to the integrity of the system, since the 2006 failure, on areas of existing and susceptible integrity hazards/threats. b) a process for determining the root-causes of abnormal operating condition events and their associated effects on the integrity of the sulphur pipeline system, which shall be linked to Spectra's mitigation, monitoring and prevention programs.

The Board makes Decision 2 to assure that any unknown remaining defects are not detrimental to the operation of the sulphur pipeline. Given the type of integrity assessment performed (i.e. hydrostatic testing) and discrete information provided by direct assessment at select locations (particularly regarding measurements of expanded pipe diameters between 2.3 km and 2.8 km), relevant subcritical anomalies that could lead to a subsequent failure during operation may not have been found.

4.5 Failure of Anchors and Tie-Rods

4.5.1 Findings as to Cause and Contributing Factors

Finding 10.	Failure of anchors and tie-rods was caused by out-of-balance forces associated with rupture and, or, hydraulic shock.

Failure of anchor and tie-rod assemblies during the 9 July 2006 rupture was caused by out-of-balance forces associated with rupture and, or, hydraulic shock. Anchor and tie-rod assemblies were not designed to withstand the maximum out-of-balance forces associated with a pipeline rupture; they were designed to only withstand hydraulic hammer forces anticipated during operation[23]. The tie-rod assemblies were designed to withstand a maximum horizontal load of 65 tonnes and the anchors were designed to withstand 5 tonnes; however a review performed by Spectra determined the pipeline rupture could result in out-of-balance forces equal to 100 tonnes[24].

Failure of anchor and tie-rod assemblies during the March 2007 remelt was caused by hydraulic shock. During the hydraulic shock event, anchor and tie-rod assemblies sustained damage, however the pipeline did not rupture.

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23 Jacobs email, "NEB Questions," 29 November 2006.

24 Spectra Energy Inc., Pine River Gas Plant Liquid Sulphur Pipeline July 2006 Line Breaks and Repair, 19 September 2007, 22

4.5.2 Corrective Actions Taken By Spectra

Spectra repaired all damaged anchors, tie-rods, supports and shoes prior to returning the sulphur pipeline to service. Spectra and its consultants reviewed design of anchor and tie-rod assemblies and determined that the design is acceptable for foreseeable operational dynamic events related to normal operation.

4.5.3 Decisions Relating to Prevention of Similar Future Accidents

The Board has no additional decisions to make in this respect. The purpose of the anchors and tie-rods is to balance restraint of the pipeline with the flexibility to absorb forces associated with hydraulic shock. In the interest of maintaining that balance, the Board accepts Spectra's determination that the design does not need revision at this time.

Chapter 5

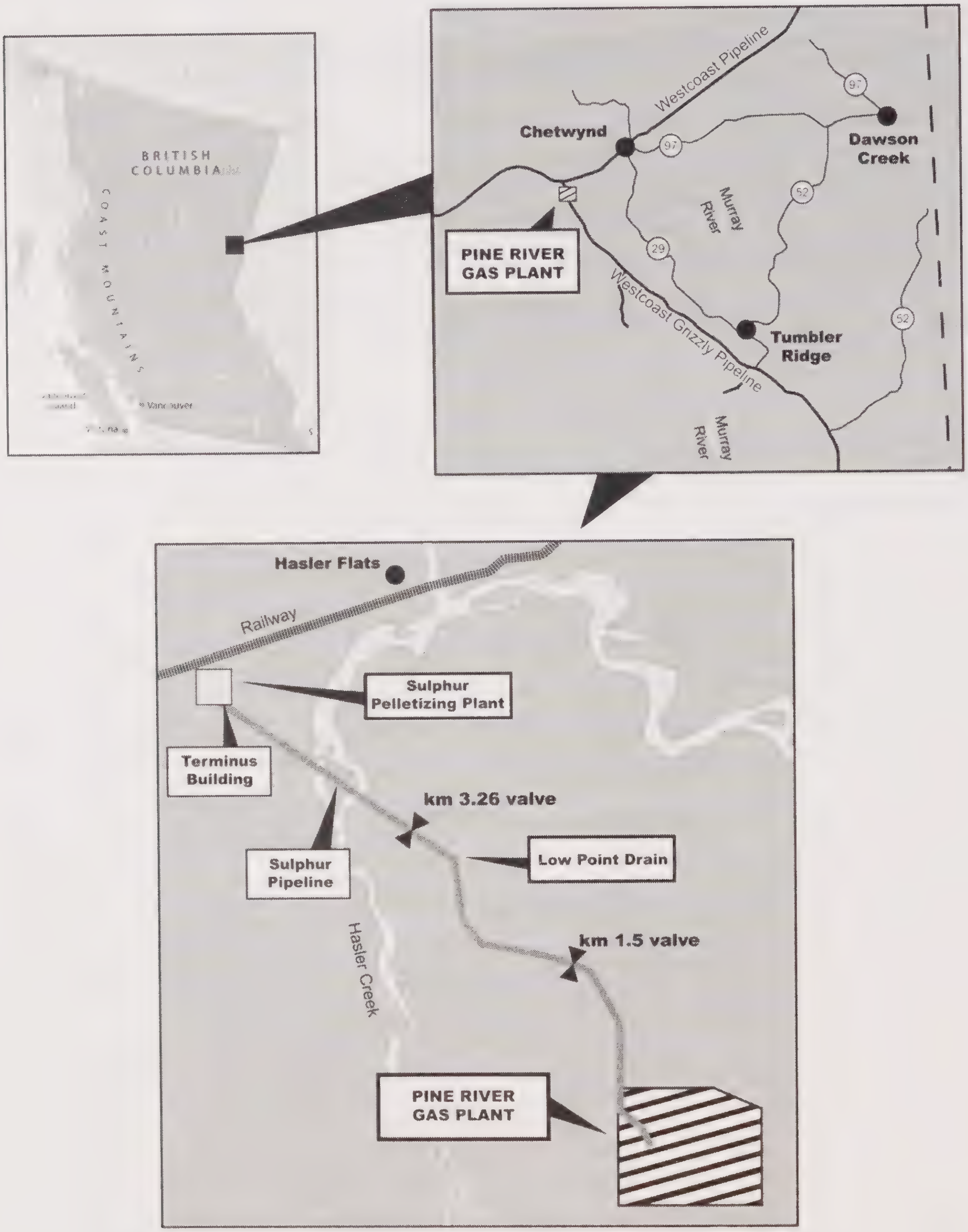
Conclusions

A summary of the findings as to the causes of the accident and factors contributing to it may be found in Appendix VIII. The Board is satisfied that causes and contributing factors have been appropriately identified.

Spectra has determined the greatest risk to integrity of the sulphur pipeline is operational upset. Spectra has made appropriate changes to procedures, equipment, and systems to mitigate these risks. In its current state, the sulphur pipeline is safe for normal operation. The Board has made two (2) decisions (summarized in Appendix IX) to further mitigate and minimize any remaining risks. Pursuant to paragraph 12(1.1)(c) and subsection 48(1.1) of the NEB Act, these decisions have been incorporated as conditions in Order SC-W102-01-2009(Appendix X).

Appendix I

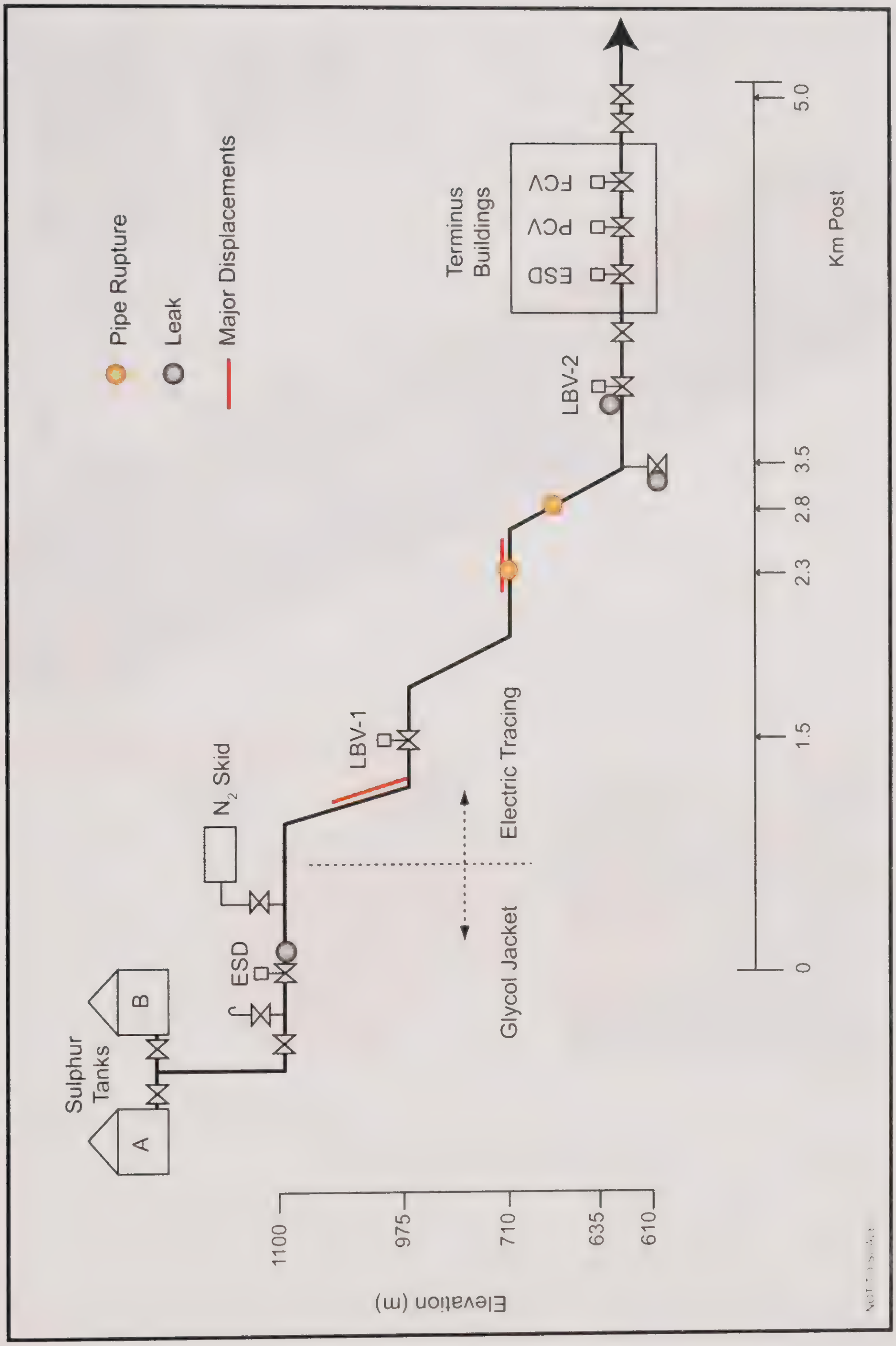
Geographic Location of the Sulphur Pipeline



not to scale

Appendix II

Schematic Diagram of Sulphur Pipeline Damages



Appendix III

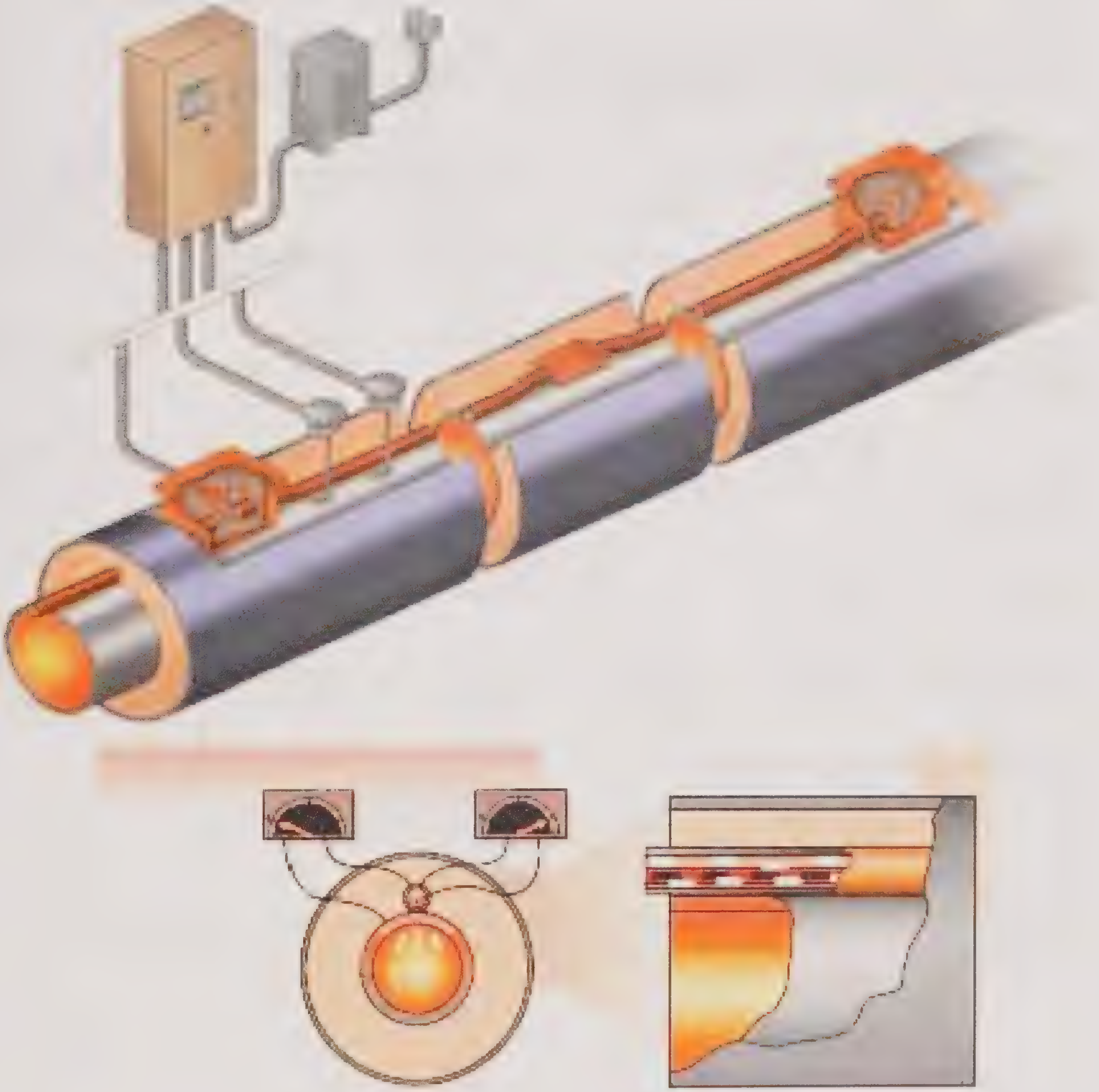
Properties of Sulphur

Table III-1: Properties of Sulphur

State	Structure	Temperature	Specific Volume
Solid	Rhombic	Less than 95.6°C	4.84×10^{-4} m^3/kg
Solid	Monoclinic	95.6°C to 115.2°C	5.12×10^{-4} m^3/kg
Liquid	---	115.2°C	5.54×10^{-4} m^3/kg

Appendix IV

SECT Therm-Trac Illustration



Note: Illustration provided by Spectra.

Appendix V

Destructive Test Results

Sources:
Acuren Group Inc., Pine River Sulfur Line: Elbow Failure, 29 August 2006.
Acuren Group Inc., Pine River Sulfur Line: Pipe Failure, 29 August 2006.

Table V-1: Tensile Test Results

Property	Yield Strength		Ultimate Tensile Strength		Elongation	
	Test	Spec	Test	Spec	Test	Spec
Elbow	354 MPa (51.4 ksi)	241 MPa (35 ksi)	501 MPa (72.6 ksi)	414 – 552 MPa (60 – 80 ksi)	31%	30%
Pipe Longitudinal (0.43" x 1.50")	425 MPa (61.6 ksi)	241 MPa (35 ksi) min	539 MPa (78.1 ksi)	414 MPa (60 ksi) min	33 %	28.5% min
Pipe Longitudinal (0.43" x 0.50")	442 MPa (64.1 ksi)	241 MPa (35 ksi) min	558 MPa (80.9 ksi)	414 MPa (60 ksi) min	24 %	22.5% min
Pipe Longitudinal (at 270°F)	447 MPa (64.9 ksi)	n/a	554 MPa (80.3 ksi)	n/a	19 %	n/a
Pipe Transverse (0.39" x 1.50")	498 MPa (72.2 ksi)	241 MPa (35 ksi) min	573 MPa (83.1 ksi)	414 MPa (60 ksi) min	24 %	16.5% min

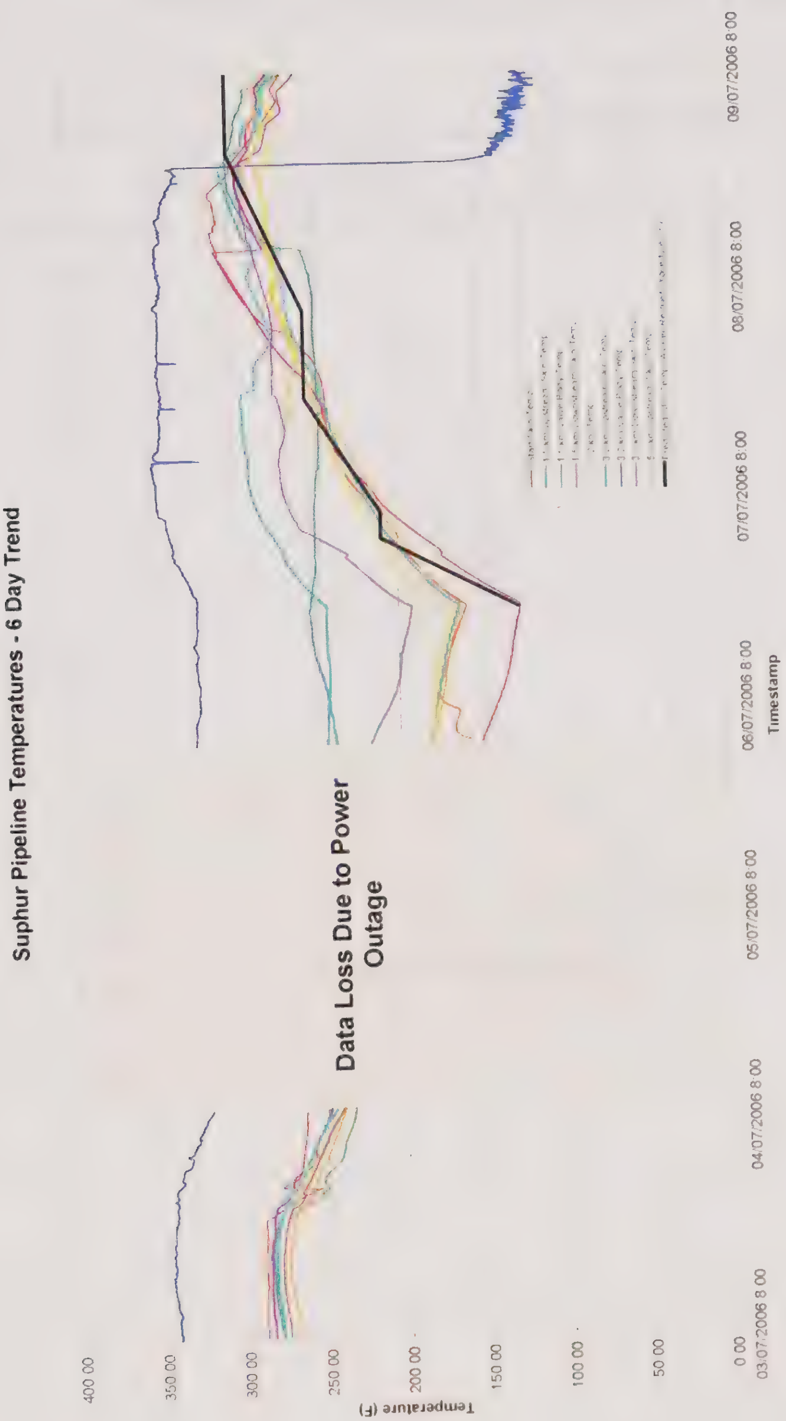
Table V-2: Charpy Impact Results

Test Temperature (°C)	Impact Energy
+80	70.5 J (52 ft-lbf)
+20	21.7 J (16 ft-lbf)
-5.0	2.7 J (2 ft-lbf)

Note: Test conducted on 6.67 mm x 10 mm x 55 mm subsize transverse body specimens, as per CSA Z245.1-02. Specimen taken from 2.3 km pipe fracture surface parallel to the plane of failure.

Appendix VI

Sulphur Pipeline Time-Temperature Profile



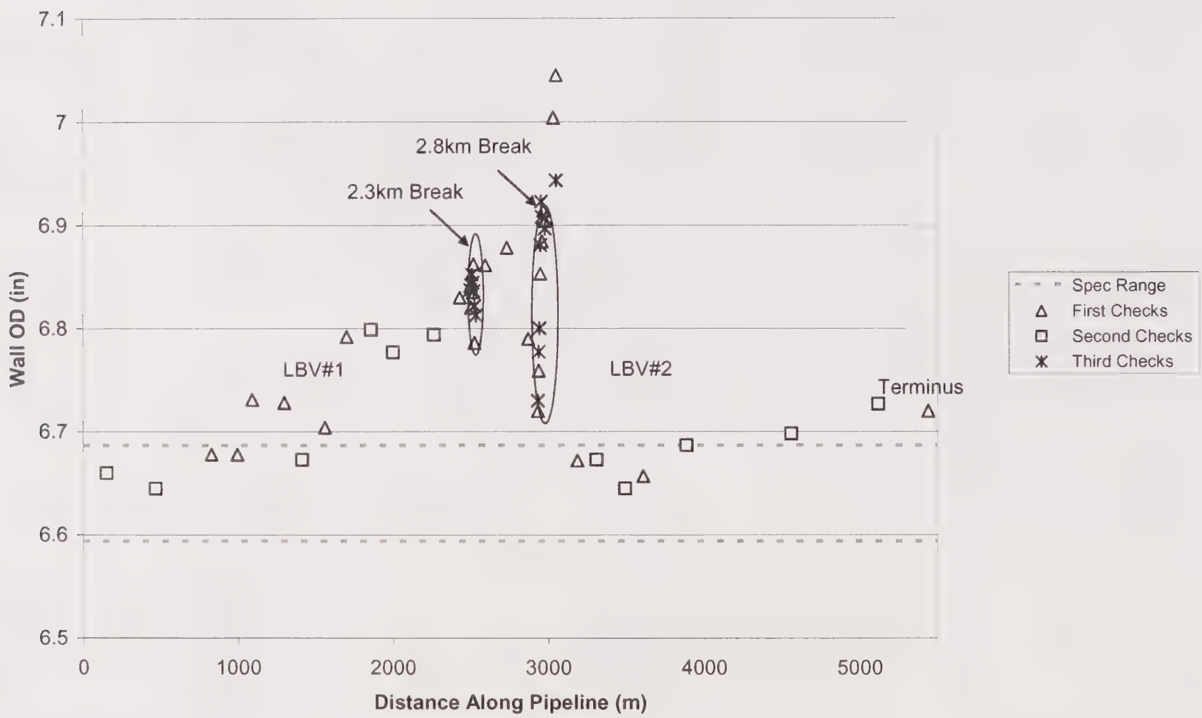
Note: Graph obtained from Spectra DCS

Appendix VII

Measurements of Outside Diameter and Wall Thickness Along the Sulphur Pipeline

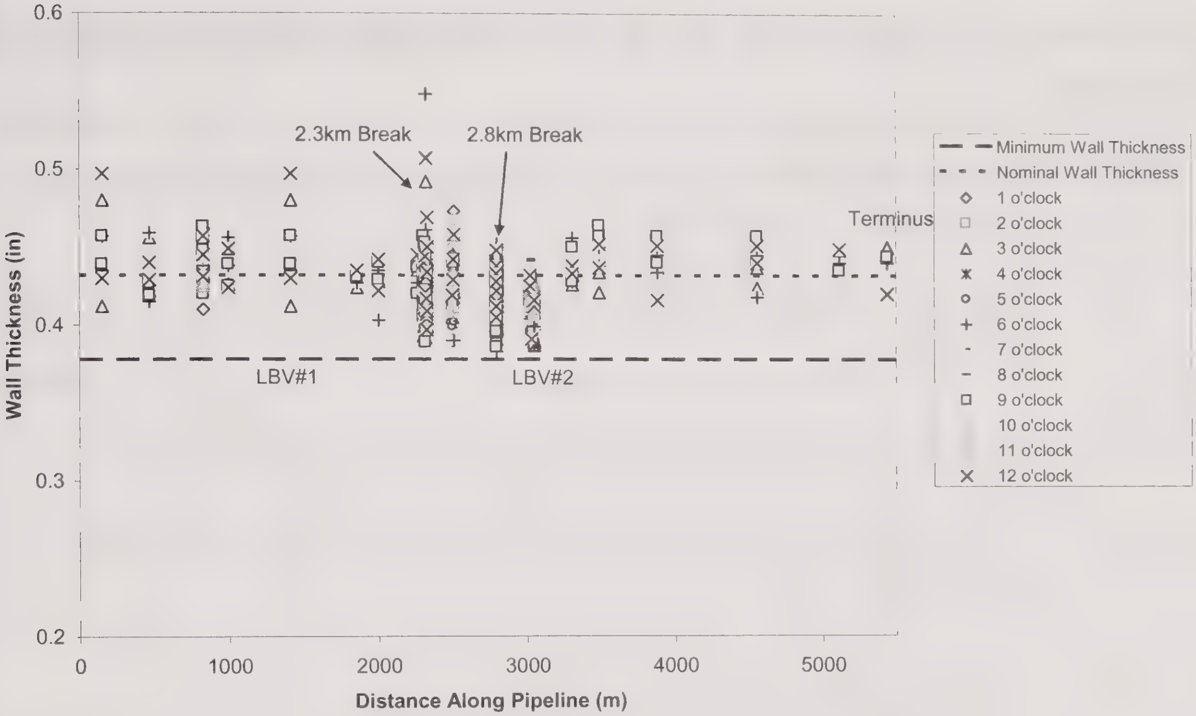
Source:
RTDs-Calipers-UT List for Sulfur Pipeline - Rev 1.xls, provided by Spectra[25]

Figure VII-1: Sulphur Pipeline Outside Diameter Measurements



[25] Note: File provided by Spectra provided the plot in Figure VII-1; Figure VII-2 was plotted by NEB from wall thickness data.

Figure VII-2: Sulphur Pipeline Wall Thickness Measurements



Appendix VIII

Summary of Findings as to Cause and Contributing Factors

Finding 1. The total loss of power at the Pine River Gas Plant was caused by a lightning strike within 2 km of the Plant.

Finding 2. Inadequate surge protection and lack of redundant or emergency power to black-start the Plant were factors contributing to the total loss of power at the Pine River Gas Plant.

Finding 3. The root cause of solidification of sulphur within the pipeline was inadequate planning for prolonged total loss of power.

Finding 4. Factors contributing to solidification of sulphur and the formation of sulphur plugs include:

a) The inability to drain the pipeline.
b) The inability to continue operation after loss of power to the DCS.
c) Inoperable electrically powered heat tracing.
d) Higher heat loss at pipeline supports, pull-boxes and junction boxes, and other discontinuities.

Finding 5. The overpressure at 2.8 km was likely caused by expansion of sulphur during phase change from solid to liquid between plugs of sulphur.

Finding 6. The overpressure at 2.3 km may have been caused by pressure or rarefaction wave, or hydraulic shock, resulting from the 2.8 km rupture in combination with the expansion effects of melting sulphur.

Finding 7. The root cause of overpressure was an inadequate remelt procedure.

Finding 8. The immediate cause of failure at both the 2.3 km elbow failure and the 2.8 km pipe failure was stress exceeding the tensile strength of the material.

Finding 9. A crack in the heat affected zone of the weld joining the SECT conduit to the pipe was a contributing factor of the rupture at 2.8 km.

Finding 10. Failure of anchors and tie-rods was caused by out-of-balance forces associated with rupture and, or, hydraulic shock.

Appendix IX

Summary of Decisions

Decision 1. Spectra shall within six (6) months of the published date of this report, submit to the Board a summary report assessing all existing operating gas plants within its NEB regulated operating system for:

a) adequacy of surge protection installations, particularly regarding whether upgrades similar to those implemented at the PRGP are warranted; and
b) availability of emergency power for black-start of generators.

Decision 2. Spectra shall, within six (6) months of the published date of this report, submit to the Board:

a) a proposed plan for conducting ongoing periodic assessments of the integrity of the sulphur pipeline system based on sound engineering principles and related industry-recognized standards. Consideration shall be given to the effects of the normal and abnormal operations to the integrity of the system, since the 2006 failure, on areas of existing and susceptible integrity hazards/threats.
b) a process for determining the root-causes of abnormal operating condition events and their associated effects on the integrity of the sulphur pipeline system, which shall be linked to Spectra's mitigation, monitoring and prevention programs.

Appendix X

Order SC-W102-01-2009

IN THE MATTER OF the investigation an accident, pursuant to section 12 of the *National Energy Board Act* (the Act), experienced by Westcoast Energy Inc. carrying on business as Spectra Energy Inc. (Spectra) on 9 July 2006; under National Energy Board (the Board) File: OF-Surv-Inc-2006 47 01

BEFORE the Board on 25 June 2009;

WHEREAS on 9 July 2006, the Pine River Gas Plant (PRGP) sulphur pipeline (Sulphur Pipeline) experienced ruptures at 2.3 km and 2.8 km;

AND WHEREAS after Spectra undertook corrective actions, the NEB's Operations Business Unit, Business Leader advised Spectra, by letter dated 26 April 2007, that there were no outstanding concerns that precluded the return of the Sulphur Pipeline to service;

AND WHEREAS the Board conducted an investigation pursuant to section 12 of the NEB Act;

AND WHEREAS the findings as to the cause of the accident and factors contributing to it, and decisions relating to the prevention of similar future accidents are published the Board's report entitled "Investigation under the National Energy Board Act, In the Matter of 9 July 2006 ruptures of the Pine River Gas Plant Sulphur Pipeline, owned and operated by Westcoast Energy Inc. carrying on business as Spectra Energy Transmission" dated 25 June 2009 (the Report);

IT IS ORDERED, pursuant to section 12 and subsection 48(1.1) of the Act, for the expressed purpose of the prevention of similar future accidents, that Spectra may continue operation of NEB regulated gas plants subject to the following condition:

1. Spectra shall within six (6) months of this Order, submit to the Board a summary report assessing all existing operating gas plants within its NEB regulated operating system for:
   a) adequacy of surge protection installations, particularly regarding whether upgrades similar to those implemented at the PRGP are warranted; and
   b) availability of emergency power for black-start of generators.

IT IS FURTHER ORDERED, pursuant to section 12 and subsection 48(1.1) of the Act, that Spectra may continue operation of the Sulphur Pipeline, subject to the following conditions:

2. Spectra shall, within six (6) months of this Order, submit to the Board:

a) a proposed plan for conducting ongoing periodic assessments of the integrity of the sulphur pipeline system based on sound engineering principles and related industry-recognized standards. Consideration shall be given to the effects of the normal and abnormal operations to the integrity of the system, since the 2006 failure, on areas of existing and susceptible integrity hazards/threats.

b) a process for determining the root-causes of abnormal operating condition events and their associated effects on the integrity of the sulphur pipeline system, which shall be linked to Spectra's mitigation, monitoring and prevention programs.

NATIONAL ENERGY BOARD

Claudine Dutil-Berry
Secretary of the Board